

Study on Strength and Stiffness of Meranti Wood Truss with Plywood Gusset Plate Connection and Lag Screw Fastener

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ABSTRACT

Wooden truss could be one of the options to be used as structural element in both building and bridge. Wooden truss overcomes the limitation of timber with great dimension with necessary strength. In this study, the wooden truss was designed with Meranti wood type with elasticity modulus of 10,520 MPa and specific gravity of 0.8. The timber used has cross-section size of 45 mm × 45 mm, with truss frame span of 2,445 mm and height of 400 mm. The connection between the timbers was using 18 mm thick plywood with 6 mm lag screw fastener. The destructive testing that was conducted on 3 test samples showed a result that the strength of the truss was at an ultimate load of 31,042 N with a ductility ratio of 5.61. Numerical study of the truss' stiffness with this connection model resulted in stiffness degree value of 0.94.

Keywords: wooden truss, lag screw, plywood gusset plate, ultimate load, stiffness degree

1 INTRODUCTION

These days, application of environmentally-friendly building materials is being reintroduced in order to reduce other building materials that affect the environment, such as concrete that creates the greenhouse gas emissions. Indonesia as a developing country that is continuously building needs to return to nature as the source for construction material, which is wood. Indonesia has a diversity of wood species that grow in nature and could be used to support the infrastructure development such as simple building and bridges.

However, availability of wood with large dimension and necessary strength is also limited. Therefore, truss becomes one of the solutions to overcome this limitation. Truss could be shaped with various connection types. Plywood gusset plate and lag screw fastener are one of connection type that is easy to work at and with sufficient materials available (Williamson, 2002; Shan, 1990).

This study was conducted to delve deeper into the trait of the floor supporting truss with the aforementioned connection model. Destructive testing was conducted to find out the strength and stiffness of Meranti Wood truss. A numerical study was then performed to obtain the stiffness degree value from truss with aforesaid connection type.

2 EXPERIMENT DETAIL

2.1 Preparation of Wooden Truss Element

The wood type used was Red Meranti (*Shorea sp.*). The physical and mechanical traits of the timber were tested based on ASTM D2395-02 (American Society for Testing and Materials, 2008). The Meranti wood used has elasticity modulus of 10,520 MPa and oven-dry specific gravity of 0.8 with a moisture content of 14%. This test result showed that the timber used was included on wood type with E10 quality code, as stated in the SNI 7933-2013 (Standar Nasional Indonesia, 2013).

The truss on the test sample has frame span of 2,445 mm with a height of 400 mm. The horizontal, vertical, and diagonal truss elements all have the same cross-section which was square with 45 mm of size. The scheme and dimension of the test sample are shown in Figure 1 and Figure 2.

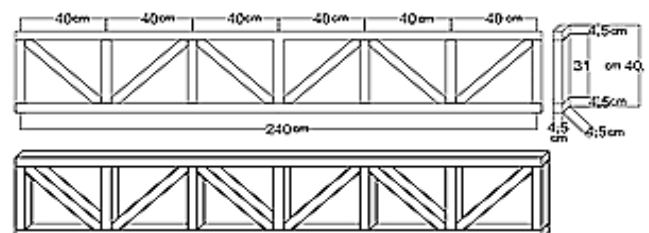


Figure 1. Scheme of wooden truss

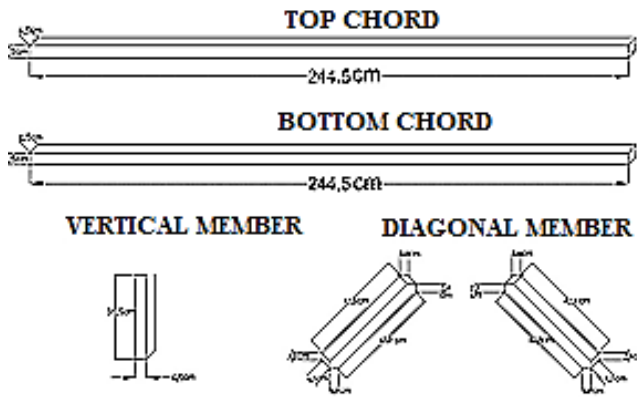


Figure 2. Element dimension of truss

2.2 Connection

Lag screw with 6 mm diameter and 4 mm length was used as fastener between the trusses using the gusset plate made from plywood. Shear strength test of the lag screw showed the maximum shear strength of 4,171.3N. While the plywood used as the connection plate has a moisture content of 11% with a specific gravity of 0.35 gr/cm³. The screw requirement was calculated based on the axial force that occurred on each timber based on a result obtained from modeling of the wooden truss with a weighting of 0.18 kN/m² (additional dead load in the form of the floor of 3 mm thick wood plate), and 1.92 kN/m² (live load).

Table 1 shows the reference design value of fastener that undergone lateral force, or on the SNI 7973-2013 (SNI, 2013) also called yield limit equation. The one that was used was the single shear value. Based on the calculation, the capacity of one lag screw was 622 N which was on mode 2 of failure modes on the connection. Figure 3 shows three test samples that were ready to be used for destructive testing.



Figure 3. Wooden truss test samples

Table 1. Yield Limit Equation – Single Shear

Yield Mode	Single Shear
I _m	$Z = \frac{D \cdot l_m \cdot F_{em}}{R_d}$
I _s	$Z = \frac{D \cdot l_s \cdot F_{es}}{R_d}$
II	$Z = \frac{k_1 \cdot D \cdot l_s \cdot F_{es}}{R_d}$
III _m	$Z = \frac{k_2 \cdot D \cdot l_s \cdot F_{em}}{(1 + 2R_e) R_d}$
III _s	$Z = \frac{k_3 \cdot D \cdot l_s \cdot F_{em}}{(2 + R_e) R_d}$
IV	$Z = \frac{D^2}{R_d} \sqrt{\frac{2F_{em} F_{yb}}{3(1 + R_e)}}$

Note

$$k_1 = \frac{\sqrt{R_e + 2R_e^2(1 + R_t + R_t^2) + R_t^2 R_e^3} - R_e(1 + R_t)}{(1 + R_e)}$$

$$k_2 = -1 + \sqrt{2(1 + R_e) + \frac{2F_{yb}(1 + 2R_e)D^2}{3F_{em}l_m^2}}$$

$$k_3 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2F_{yb}(2 + R_e)D^2}{3F_{em}l_s^2}}$$

whereas *D* is screw diameter = 6 mm; *F_{yb}* is bending yield strength of the dowel = 483 MPa; *R_d* is reduction requirement taken as 0.4*D* + 0.5 = 2.9 for *D* ≤ 6.35mm; *R_e* is *F_{em}/F_{es}* = $\frac{56}{25.9} = 2.162$; *F_{em}* is strength of the dowel bearing on the main structure component = 56 MPa; *F_{es}* is the strength of dowel bearing on the side structure component = 25.9 MPa.

R_t is *l_m/l_s* = $\frac{20}{18} = 1.11$; *l_m* is the length of dowel bearing on the main structure component (20 mm); *l_s* is the length of wedge bearing on the side structure component (18 mm). Figure 4 shows the connection scheme of truss for each joint.

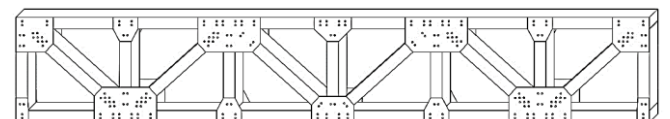


Figure 4. Connection scheme of truss

2.3 Destructive testing

Destructive testing was conducted using the UTM (Universal Testing Machine). The purpose of this test was to obtain the strength of the wooden truss (Sagara, et al., 2017). The three truss frames were tested by loading weight on 2 points on a third of the

span, and the deflection occurred up to the maximum load that could be borne (Figure 5). The adding load speed that was applied was equal to 6 mm/min.



Figure 5. Destructive testing of the truss models

2.4 Experimental Result

Figure 6 to Figure 8 show the graphic on the relation between load and deflection for three of the test samples, which was obtained from the destructive testing result. Design load, proportional load, and ultimate load, also the deflection occurred are shown on each graph.

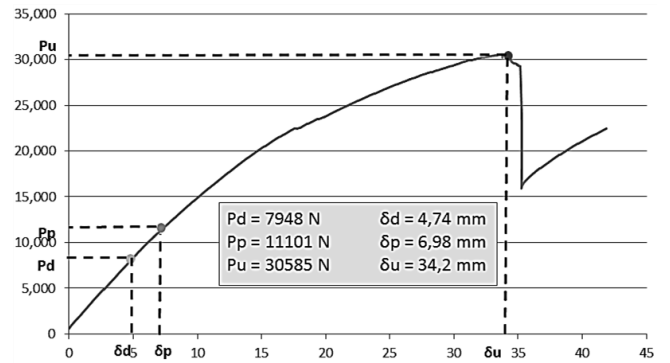


Figure 8. Graphic of load – deflection of Truss – 3

3 NUMERICAL MODEL

A numerical model was made to obtain stiffness value of the truss, and to conduct validation of the occurred deflection value that occurred in the experiment with the deflection resulted from the mode. The numeric model was made with help from the SAP2000 program. The values of material properties, such as elasticity modulus and specific gravity, were taken from the testing that has been carried out at the beginning of the experiment. The truss model was given a centralized load on the third-point in the amount of proportional load.

There were 3 types of stiffness value that were modeled. The first truss model was made with the assumption that every connection is pinned connection. The second truss model was made with the assumption that every connection was rigid connection/continuous. While the third truss model was made by using fixity partial, in which it is assuming that connection on each member of the truss has connection type between pinned connection and rigid connection.

The value of connection stiffness was calculated by Romstad and Subramanian as shown in Equation (1) (Romstad & Subramanian, 1970)

$$S_c = \frac{\lambda 4EI}{L} \tag{1}$$

whereas S_c is connection stiffness value and λ is partial fixity value of the connection. For rigid connection, λ value is 1. This means that the truss has the stiffness to defend the original angle between every member of the truss. As for the pinned connection, the λ value is 0. For the semi-rigid connection, the λ value is $0 < \lambda < 1$. Therefore, the calculation was S_c value for $\lambda = 0.1; 0.2; 0.3$; etc. up to $\lambda = 0.9$.

Figure 9 shows the SAP 2000 model that used partial fixity to the model connection between the members of the truss.

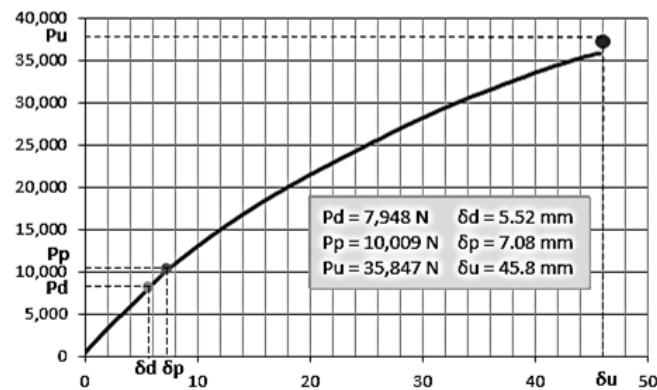


Figure 6. Graphic of load – deflection of Truss – 1

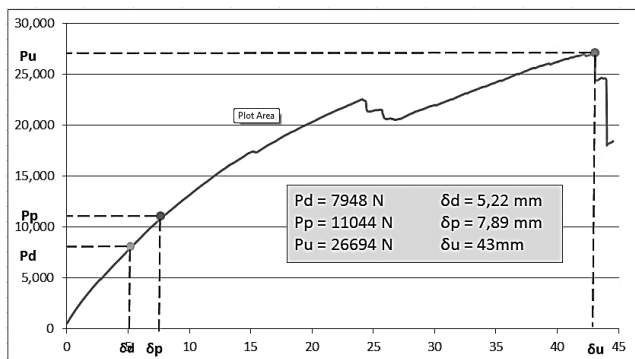


Figure 7. Graphic of load – deflection of Truss – 2

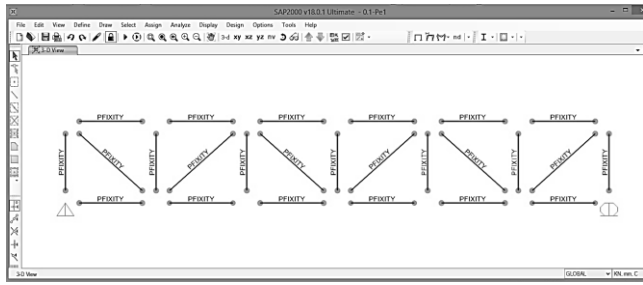


Figure 9. Truss model with partial fixity

The result of the model with $0 < \lambda < 1$ value for each proportional weighting, Pp_1 , Pp_2 , and Pp_3 , are shown in Table 2.

Table 2. Deflection from SAP2000 model analysis results

λ	Pp_1 10.01 kN	Pp_2 11.044 kN	Pp_3 11.101 kN
	δ_1 (mm)	δ_2 (mm)	δ_3 (mm)
1 (rigid)	6.99	7.82	6.91
0.9	7.11	7.95	7.03
0.8	7.11	7.95	7.03
0.7	7.11	7.96	7.04
0.6	7.11	7.96	7.04
0.5	7.11	7.96	7.04
0.4	7.12	7.97	7.05
0.3	7.12	7.97	7.05
0.2	7.13	7.98	7.05
0.1	7.13	7.98	7.06
0 (pinned)	7.14	7.98	7.06

4 RESULT AND DISCUSSION

4.1 Ductility

The result from destructive testing is shown in Table 3. P_e and δ_e are load and deflection at elastic limit whereas P_u and δ_u are load and deflection at the ultimate limit.

Table 3. Result of destructive testing on test sample truss

No	P_e (N)	δ_e (mm)	P_u (N)	δ_u (mm)
1	10,009	7.08	35,847	45.9
2	11,044	7.89	26,694	43.0
3	11,101	6.98	30,585	34.2

The result of destructive testing was then used to calculate ductility, which is a comparison between the deflections that occurred on ultimate condition to the proportional ductility (Stalnaker & Harris, 1997). It then resulted in the mean ductility of 5.61 for a truss with this connection type. The results are shown in Table 4.

Table 4. Calculation on truss ductility

No	Ultimate displacement ductility	Mean ductility
1	6.48	5.61
2	5.45	
3	4.90	

4.2 Stiffness Degree

From the result of the numerical analysis, it was obtained that Truss – 1 with $P_p = 10,009\text{N}$ and $\delta_p = 7.08\text{mm}$ on destructive testing, with partial fixity value $\lambda = 0.93$, as shown by the model. For Truss – 2 with $P_p = 11,044\text{N}$ and $\delta_p = 7.89\text{mm}$, the partial fixity value $\lambda = 0.95$, as shown by the model. While the Truss – 3 with $P_p = 11,101\text{N}$ and $\delta_p = 6.98\text{mm}$, the value of partial fixity was $\lambda = 0.95$, as shown by the model. The graph of deflection of truss can be seen on Figure 10 to Figure 12.

Therefore, the mean partial fixity value for the three test samples was 0.94.

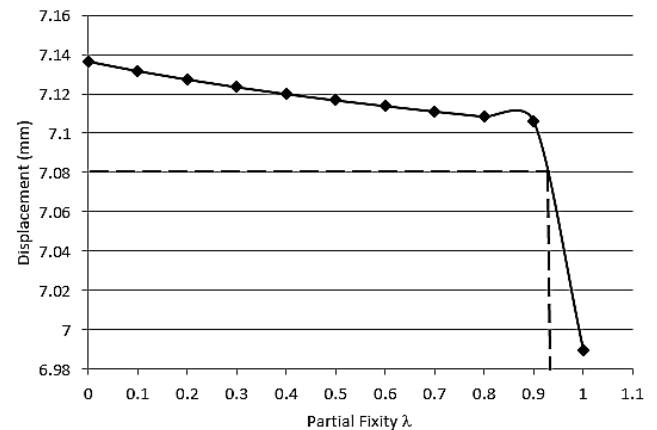


Figure 10. Deflection of truss – 1 model

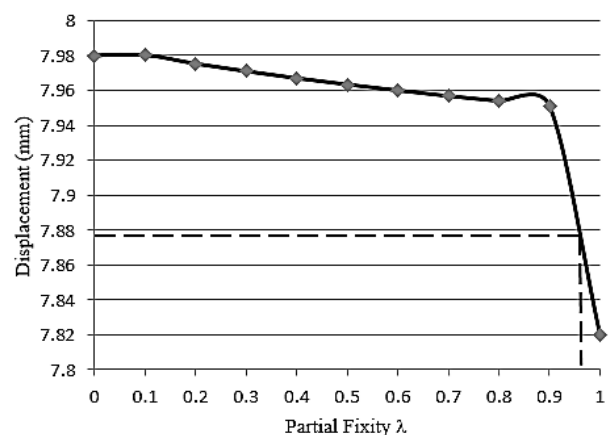


Figure 11. Deflection of truss – 2 model

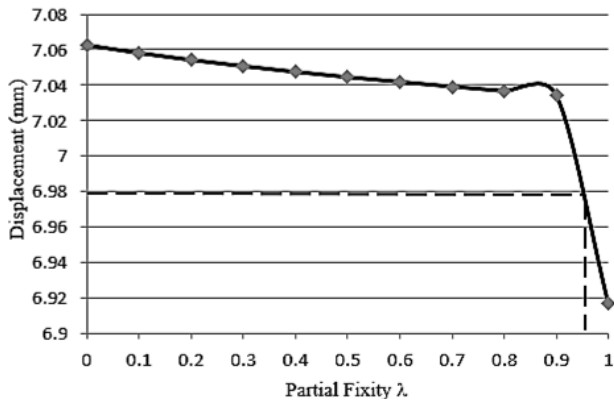


Figure 12. Deflection of truss – 3 model

4.4. Failure Modes on Wooden Truss Testing

On ultimate condition, Wooden Truss 1 and 3 have similar failure modes, which were on the first diagonal log, in which it was already known that it has the largest internal forces in the form of tensile strength. The occurred failure was ductile, is characterized by the crack that formed slowly before the log finally failed (Aghayere, 2007).

In test sample 2 and 3, the horizontal log also suffered from failure, due to the existence of knot, which then caused strength reduction in the wood. This became important when the wooden material is used as a structural element, in which it should be selectively chosen to avoid using defective wood which they could reduce the strength capacity of the wood.

Failure did not occur in the connection area because the shear stress from the lag screw combination on each connection points had not passed the maximum value. Location and typical failure modes are shown from Figure 13 to Figure 19.

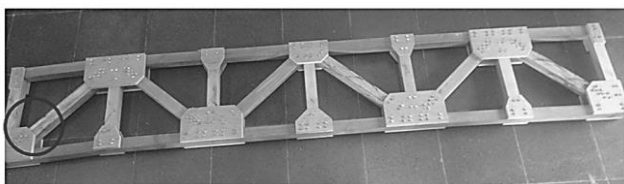


Figure 13. Failure location of Truss 1



Figure 14. Failure on diagonal log of Truss 1 caused by tensile strength

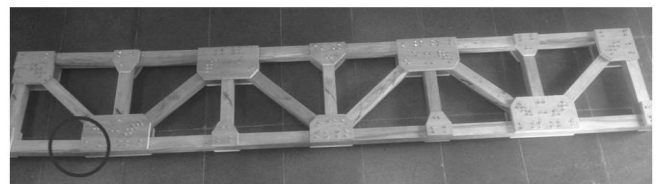


Figure 15. Failure location of Truss 2

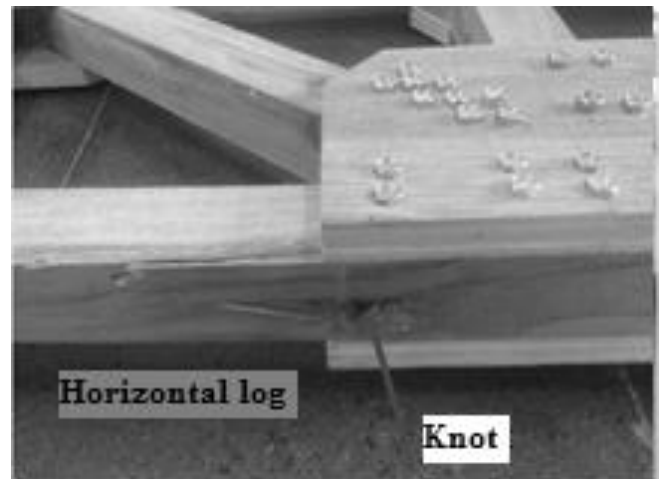


Figure 16. Failure on horizontal log of Truss 2 caused by presence of knot

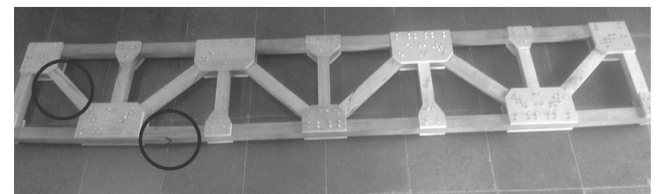


Figure 17. Failure location of Truss 3

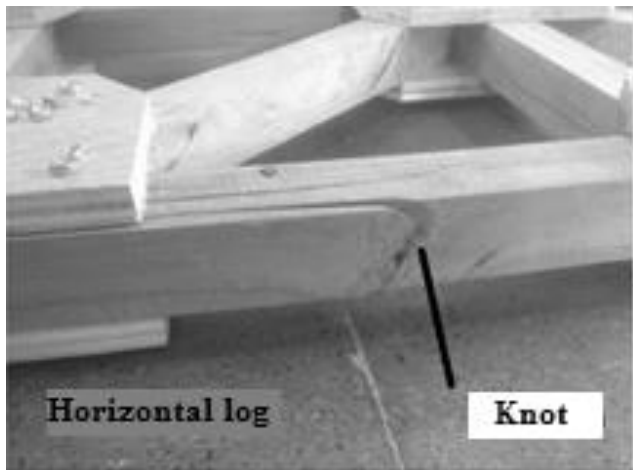


Figure 18. Failure of Truss 3 on its horizontal log caused by presence of knot

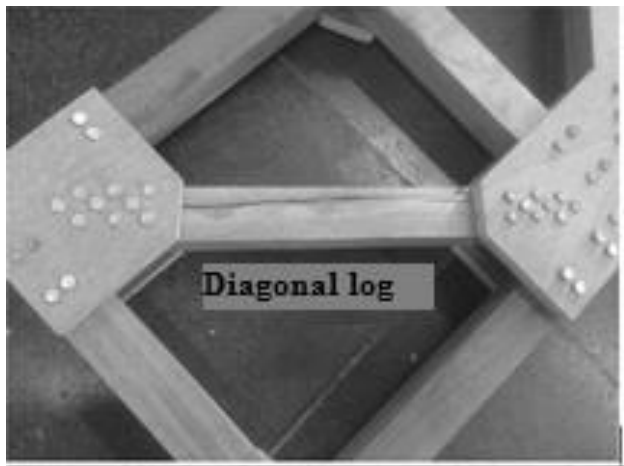


Figure 19. Failure on Truss 3 on its diagonal log caused by tensile strength

5 CONCLUSIONS

Wooden truss with plywood gusset plate connection and lag screw fastener that was used as floor supporting truss has an adequate safety factor, which was 1.35 in proportional condition, and 3.91 on ultimate condition. Wooden truss has stiffness on the connection that located between the pure pinned connection and pure rigid connection. The numerical model showed that the stiffness degree value (partial fixity) from three of the truss test samples was of 0.94. The ductility value from the displacement of this connection was of 5.61.

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